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AEROSOL MODELLING FOR OPTICAL WEATHER

Final Report

D. Deirmendjian, Principal Investigator

July 1980

U.S. Army Research Office

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A review of recent literature indicates that there has been fairly good progress in the understanding of the growth of aerosols with increasing relative humidity. However the forecasting of visibility on the basis of meteorological parameters alone is possible with moderate success only.

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ON THE PROBLEM OF FORECASTING THE OPTICAL WEATHER

1. Introduction

Tropospheric air, particularly in the near surface layers, always contains a certain number of *aerosol particles* (larger than air molecules but smaller than large hydrometeors such as cloud and raindrops, cirrus particles, and snow or hail), which determine the degree and type of *particulate turbidity*. The nature, amount, size distribution, vertical and horizontal distribution, and their time dependence may all be quite variable as functions of prevailing meteorological conditions (the weather), geographical location and type of terrain (or sea state), season, etc. Particulate turbidity together with the permanent and some variable gaseous components of air, determine what G. V. Rozenberg has called the local *optical weather* which controls such things as the spectral transmissivity of air, brightness and polarization of the sunlit sky, indirect illumination of objects, etc. The optical weather thus affects the operational efficiency of active and passive optical and infrared sensing and discrimination systems. It is therefore important to be able to somehow specify and perhaps even to predict--within more-or-less broad limits--the optical weather for military and other applications which depend on it.

Whereas in recent decades there has been considerable progress in *describing* the optical weather in terms of the absorption and scattering properties of individual particles and their aggregates and the radiative transfer resulting from their embedment in atmospheric air, there is as yet no general capability to *predict* such weather--which is tantamount to predicting the level and nature of turbidity--even within more-or-less broad limits. In principle this rather complex problem could be solved provided (a) we have sufficient information on prime aerosol sources and sinks, and (b) we understand the microphysical, chemical and other related mechanisms governing the evolution and stability of aerosol systems. At present neither of these two conditions are completely satisfied although there is an increasing amount of research effort directed toward them.

2. Some Recent Work on Aerosol Modelling

In particular, one of the problems faced in military surface operations is precisely the difficulty of obtaining a reliable prediction of local visibility or air transmissivity in the visual and near infrared regions of the spectrum. Outside gas absorption bands, this will depend mainly on the attenuation of a beam of electromagnetic energy by Rayleigh and large particle (aerosol) scattering and absorption. To predict these effects one in turn needs to estimate the value of certain parameters such as the size and size spectrum $n(r)$ of the particles, their total number N per unit volume, their vertical distribution $N(z)$ near the ground, and their composition represented by the complex index of refraction $m = \nu - ik$. These values are to be deduced from the latest available measurements by means of extrapolation or by theoretical modelling and prognostication. Just measuring these parameters over the terrain of interest is itself not easy, requiring the use of sophisticated instrumentation and its operation.

As already mentioned, the values of the above aerosol parameters must depend on many variables. Besides the usual meteorological parameters, for example, such as temperature T, pressure P, relative humidity $R\%$, absolute humidity H, and the three-dimensional field of motion, u,v,w, one needs data on the local and surrounding terrains, type of air mass, and its history before arriving over the terrain. Furthermore, the functional relationship between these parameters and the aerosol characteristics is not always clearly established.

It has been long known that, under certain conditions, the atmospheric attenuation coefficient, $\beta_\lambda[n(r),m]$, at least within the visible and near infrared spectrum free of gas absorption lines, depends directly on the ambient relative humidity $R\%$ and the temperature T. Only quite recently, however, have there been systematic and detailed measurements, both in the open air and in the laboratory, of that relationship. The presumption here is that it should suffice to forecast the local relative humidity in order to deduce the attenuation coefficient due to aerosols.

In fact, as indicated by a survey of the recent literature, the question is only partially answered because the modification of the aerosol characteristics does not depend on R% and T alone. Judging from the volume of published papers, there is considerable interest in the subject of the dependence of $\beta_\lambda[n(r),m]$ on the relative humidity R% and other parameters. In this brief overview we can discuss only a small part of this literature, namely those papers that seemed to us particularly relevant or of major impact on account of the extent and reliability of experimental data. Nor is this literature confined to the U.S.A. and Western Europe, for the Soviets, particularly the Russian scientists, seem to have a good hold on the subject, both experimental and theoretical.

For example, G. V. Rozenberg and his associates in Moscow's Institute of Physics of the Atmosphere must have early become interested in the above-mentioned problem, and a good measurement program seems to have been instituted and sustained at least since 1972. In a joint paper with Georgiyevskiy [1] it was shown that even at low relative humidities $20 < R\% < 30$ the effects of condensation are optically discernible with increasing R%, whereas changes in *absolute* humidity, i.e., water content, do not affect visibility. They also find that it is the submicron particles in the population that affect the extinction coefficient most, a result which is borne out by other workers.

Another interesting paper by Georgiyevskiy et al. [2] discusses the question of observed size distributions of aerosols, together with a statistical analysis including simultaneous observation of $\beta_\lambda[n(r),m]$ in the visible and infrared range. They find (among other things) that the correlation coefficient between number of particles and R% is highest for the "finely dispersed" ($r < 0.5$ μm) portion of the aerosol population. Also they find that the size distribution function cannot be represented by any one law, certainly not by the Junge type.

The amount of water uptake and equilibrium sizes of a particle under high humidity conditions ($R\% \geq 95$) were studied in depth--both experimentally and theoretically--by Thudium [3]. Among other interesting results, he finds that the mass ratio of the water soluble

part and the entire aerosol particle may be derived from an analysis of aerosol deposits. The chemical composition thus obtained largely determines the water uptake and equilibrium sizes of the aerosol particles. This work is corroborated and refined by Hänel and Zankl [4] for the case of a mixture of electrolytes, again at high R%. They find that, within certain limits, the water uptake for a mixture of salts is closely approximated by adding the expected uptakes of the individual components of the mixture.

In passing let us note that Tomasi and Tampieri [5] had found a direct correlation between visibility V and the empirical coefficient b in the relation

$$V = bw^{-2/3} \tag{1}$$

where w is the liquid water content. This seems to contradict Georgiyevskiy and Rozenberg's [1] above-mentioned finding. We note, however, that Tomasi and Tampieri do manage to successfully fit "modified gamma" size distribution functions of the type introduced by this author [6,7] without recourse to the Junge type of distribution which is favored by many authors and which is incapable of representing the observations according to Ref. 1.

Finally, the very recent and interesting paper by Nilsson [8], which is a follow-up of its precursor by Hågård et al. [9], deserves mention. In it the author seems to have attacked a problem somewhat parallel to the one we had initially formulated in a recent proposal to the Army Research Office (submitted 4/6/79), that is, to investigate the possibility of forecasting visible and infrared transmissivity in terms of meteorological parameters. Nilsson [8] arrives at conclusions, e.g., about the influence of R% on the size distribution and hence extinction, quite identical with those reached previously by Soviet workers [1,2] and German ones [3,4], although he does not mention them. He estimates $\beta_\lambda[n(r),m]$ in the infrared by modelling the particle spectrum of various air masses in terms of the meteorological visibility, then calculates the evolution of the size distribution in the presence of various humidities R%. However, by his own admission,

the initial distributions and growth mechanisms are not absolutely reliable and further field studies are recommended.

We should also mention here a very recent work by Shettle and Fenn [10], available in report form, which is closely related to our theme. In it they have prepared quite detailed tables of $\beta_\lambda[n(r),m]$, based on Mie calculations using composite refractive index values obtained semi-empirically, listed as a function of wavelength, model size distributions, and relative humidities. The degree of confidence with which one may rely on such tables to reproduce real situations remains to be ascertained, as the authors themselves caution the reader.

3. Concluding Remarks

The foregoing brief overview indicates that there is enough knowledge in the field to allow in certain cases the development of a reasonable capability to forecast the type, size and concentration of *natural* aerosol, to be expected under given meteorological conditions and over a given type of terrain. From this the transmissivity or $\beta_\lambda[n(r),m]$ of the lowest layers of the atmosphere can be deduced, provided the chemical composition, size distribution of the "dry" aerosol and relative humidity are *accurately* forecast. It is evident that even with the best models the transmissivity may be forecast with moderate accuracy only.

The above "conclusions" must be considered preliminary and tentative, based as they are on the present brief overview of recent published literature. Anything more reliable and definitive requires a more comprehensive review and research effort than was possible under the present contract.

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